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(54) METHOD AND APPARATUS FOR PRODUCING STRIP MATERIAL

(71) We, HEAD WRIGHTSON & COMPANY LIMITED, a Company organised under the laws of Great Britain, of The Friarage, Yarm, Cleveland, TS15 9DA, do hereby declare the invention, for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to methods and apparatus for producing strip material, in particular strip metal.

Ductile material, particularly metals such as steel, are generally produced in a rolling mill in which a billet of the material is passed between successive pairs of rolls, the spacings between each pair of rolls decreasing until the billet has been rolled into a strip of desired thickness.

Adjacent longitudinal sections (often referred to as "fibres") of strip produced by such rolling mills are often of different lengths, which result in an uneven strip. Further treatment of the strip material is therefore usually necessary in order to obtain a flat strip.

It is possible to exercise some control over the flatness of the rolled strip material by varying the distribution of pressure applied across the strip material by the last pair of rolls in the strip mill. Thus, in one system which has been proposed previously the strip leaving the last pair of rolls of the strip mill is passed over a pressure sensitive roll which comprises a coaxial set of rollers extending across the strip, each roller being supported on an air bearing. By measuring the air pressure in each air bearing the transverse distribution of tension in the strip can be determined. Since this tension distribution is related mathematically to the flatness of the strip, flatter strip can be obtained by controlling the pressure distribution in the last pair of rolls in the strip mill in response to the air pressure distribution in the air bearings.

This arrangement suffers from the disadvantages that the air pressure distribution can not, in every case, be accurately related to the tension distribution across the strip, and that the mill rolls are generally of a construction which is insufficiently flexible to allow fine variations of the pressure applied across the strip.

We have now found that the control over the flatness of the strip produced in a rolling mill can be improved by subjecting the strip to the so-called stretch-levelling process when it leaves the last pair of rollers in the rolling mill. The stretch levelling process which is well known to those skilled in the art, involves stretching adjacent longitudinal sections of the strip sufficiently to exceed the elastic limit of the material from which the strip is composed so that, when the strip is released from tension all the adjacent sections of the strip are of substantially the same length.

The stretching can be effected by application of pure tension forces to the strip. Preferably however the stretching is effected by subjecting the strip to a plurality of bend reversals under tension, as for example described in our earlier British Patent Specifications No. 1,122,081, 1,219,966, 1,219,967 and 1,394,083.

The work performed on the stip in reducing its thickness causes the generation of heat in the strip. This heat is dissipated partly by the air surrounding the strip and partly by the mill rolls. The heat is removed from the mill rolls mainly by lubricant in the bearings of the rolls and their backing rolls. Since the bearings of the rolls and the backing rolls are normally located at the sides of the rolls, conduction of heat in the rolls occurs in directions from the centres of the rolls toward the ends of the rolls. As a result, the temperature of the rolls is usually higher in the centres of the rolls than at the ends. Although transverse temperature variations in the rolls can be off-set to some extent by using sprays of coolant, it is nevertheless difficult to obtain a uniform temperature across each roll.

The temperature of the strip leaving the last pair of rolls of the rolling mill usually therefore varies across the strip. In materials having relatively high coefficients of linear

expansion therefore, these temperature variations can themselves produce uneven strip. The invention therefore particularly provides a method of producing strip material which comprises rolling strip material to a desired thickness, placing the rolled strip under tension, measuring the temperature of the strip material at selected points across its width and stretching the strip material non-uniformly across its width by amounts dependent upon the temperature measurements and sufficient to reduce or eliminate differences in the lengths of adjacent longitudinal sections of the strip material which would otherwise occur on releasing the tension and on cooling the strip material to a uniform temperature.

The stretching necessary to reduce or eliminate the differences in lengths of adjacent longitudinal sections of the strip material is preferably effected by subjecting the strip material, whilst under tension, to a plurality of bend reversals about axes transverse to the strip and adjusting the transverse profile to which the strip is bent in at least one of the bend reversals by an amount dependent upon said temperature measurements so that the relative lengths of adjacent longitudinal sections of the strip material are increased sufficiently to offset differences in their lengths which would otherwise occur on bringing the strip to a uniform temperature.

The preferred method of the invention is conveniently carried out on apparatus which comprises means for rolling the strip material to a desired thickness, means for placing the rolled strip under tension, means for measuring the temperature of the strip material at selected points across its width, said means for placing the strip under tension including a plurality of transverse bending rolls, at least one of which may have its profile adjusted in dependence upon said temperature measurements, and means for drawing rolled strip material in a longitudinal direction over the bending rolls whilst under tension.

The or each adjustable bending roll preferably comprises a flexible roller supported by a plurality of backing rolls and means for adjusting the relative radial dispositions of the backing rolls in dependence upon said temperature measurements.

In one preferred construction, the flexible roller is supported between backing rollers rotatably mounted on two parallel flexible shafts each supported along its length by a plurality of bearings movable radially relative to each other by means of reciprocable wedges. Advantageously, each wedge is reciprocated by rotating a lead screw.

The profile of the or each adjustable bending roll is preferably adjusted automatically as appropriate to compensate for any differential contraction of adjacent longitudinal sections of the strip material on cooling. The temperature sensing means may produce electrical signals representative of the temperature of the strip at selected points across its width, and these signals may be used to control the adjustment of the or each adjustable bending roll, by means of a conventional electronic feedback control circuit.

The tension necessary to stretch the strip material may be provided by two sets of bridle rolls positioned upstream and downstream of the bending rolls. The strip material is wrapped around the bridle rolls, which are driven separately at different speeds, thus generating tension in the strip material. In some cases, however, for example where relatively thin and/or ductile strip material is being produced, the bridle rolls may be omitted and the tension necessary for the stretching may be generated downstream from the last pair of rolls in the rolling mill by a coiling mechanism alone.

In order that the invention may be better understood, a preferred embodiment thereof will now be described, by way of example only, with reference to the accompanying drawings, in which:—

Figure 1 is a diagram illustrating the arrangement of apparatus used in the preferred method of the invention;

Figure 2 is an elevation of part of the apparatus illustrated in Figure 1;

Figure 3 is a vertical cross-section of the apparatus of Figure 2;

Figure 4 is a plan view of the apparatus shown in Figures 2 and 3;

Figure *5a* is a graph showing a typical temperature distribution across the strip, and

Figure *5b* shows schematically a deflected flexible roller.

Referring to Figure 1, strip material 1, in this case steel strip, is rolled to a desired thickness in a rolling mill the last pair of rolls of which is indicated at 2. The mill illustrated is designed to roll cold strip material. The invention is, however, equally applicable to hot rolling mills, i.e. rolling mills designed to roll hot strip material. The rolls 2 are of conventional construction and the spacing between the rolls through which the strip 1 passes may be varied by means not shown so that the operator may control the thickness of the strip 1.

The strip 1 emerging from the rolls 2 passes over a first deflector roll 3 and is wrapped around a first pair of bridle rolls 4, 5. The strip then passes over a second deflector roll 6, a set of four generally parallel bending rolls 7, 8, 9, 10, arranged transversely to the strip 1, a third deflector roll 11, and around a second pair of bridle rolls 12, 13. The strip emerging from the second pair of bridle rolls 12, 13 passes over a fourth deflector roll 14 and is coiled onto a reel 15.

The two pairs of bridle rolls 4 and 5, 12 and 13, are each rotatably mounted in a

respective frame 16, 17, the two frames 16, 17 being themselves mounted for rotation about horizontal axes through about 220° between operating positions, indicated in full lines in Figure 1, and threading positions, illustrated in broken lines in Figure 1. Each bridle roll 4, 5, 12, 13 is driven by a respective direct current motor and is provided with a digital tachometer which gives a visible display of the speed of rotation of the roll at any time.

Three of the bending rolls 7, 8, 9 are of conventional construction each being supported by a respective set of backing rolls (not shown). The two upper rolls 7, 9 and their associated backing rolls are mounted on a frame for movement towards and away from the lower bending roll 8.

The fourth bending roll 10, which has an adjustable profile, is illustrated in more detail in Figures 2 and 3.

As seen in Figures 2 and 3, the bending roll 10 is a flexible roller supported by thirty-two backing rollers 20 arranged in two rows 21, 22 of sixteen on opposite sides of a vertical axial plane of the flexible roller 10. Each set of rollers 21, 22 is rotatably mounted on a respective shaft 23, 24. The roller 10 and the shafts 23, 24 are rotatably carried in mountings 25, 26 and each shaft 23, 24 is also supported along its length by a set of sixteen bearings 27, 28, mounted on a set of eight base plates 29, one pair of bearings for each shaft being carried by each base plate 29. The base plates 29 are themselves a sliding fit within a trough 31 in a supporting frame 30 for the roll 10, the trough 31 being defined by two keep plates 32, 33 and a bottom plate 34.

Each base plate 29 is provided with an inclined under-surface which engages with a respective wedge 35 reciprocable within the trough 31 by means of a respective lead screw 38 rotatably mounted in the keep plates 32, 33. Each of the eight lead screws 38 is rotatable by a drive gear 40 and the drive gears 40 are coupled in pairs to four main drive wheels 42 by means of four intermediate gear wheels 44. Each main drive wheel 42 is rotatable through a respective gearbox 45. The gearboxes 45 are driven either electrically or by means of respective hand-wheels (not shown).

A temperature sensing unit 50 is positioned downstream from the fourth bending roll 10 and comprises six individual temperature sensing devices such as thermopiles or infra-red detectors mounted above or below the strip 1, and spaced equally across the width of the strip in order to measure temperatures at points across the width of the strip. The outputs from the detectors are converted into a visible display of the temperature of that part of the strip above which they are mounted i.e. to give a visual display of the temperature profile across the strip.

The strip 1 is fed from the fourth deflector roll directly onto the reel 15 which is of conventional construction. If desired, a storage loop may be provided between the fourth deflector roll and the reel 15 to allow strip material already coiled onto the reel to be stopped and removed whilst the mill is being operated continuously.

The operation of the mill is as follows:—

The strip 1 emerges from the last pair of rolls 2 of the rolling mill with an uneven transverse temperature profile. With the bridle rolls 4, 5, 12, 13 in the threading position illustrated by broken lines in Figure 1, and the upper bending rolls 7 and 9 spaced from the lower rolls 8, 10, the strip 1 is fed from the rolling mill over the first deflector roll 1, along the path between bridle rolls 4 and 5, 12 and 13 indicated by a chain-dotted line, over the fourth deflector roll 14 and on the reel 15. The bridle rolls 4, 5 and 12, 13 are then rotated into their working positions, indicated in full lines, so that the strip becomes wrapped in around the bridle rolls 4, 5, 12, 13 in the sinuous path shown in Figure 1.

The upper bending rolls 7, 9 are then brought down into engagement with the strip 1 so that the strip is bent over each of the rolls 7, 8, 9. The drive motors of the bridle rolls 4, 5, 12, 13 are then operated so that the strip is placed in tension over the bending rolls 7, 8, 9, and the pressure exerted by the bending rolls is then adjusted so that, during its passage over the bending rolls 7, 8, 9, the strip is subjected to bend reversals which stretch each adjacent longitudinal section of the strip sufficiently to exceed its elastic limit, therby bringing each of the adjacent longitudinal sections of the strip to the same length under the prevailing temperature conditions of the strip.

In order to compensate for unequal changes in length of adjacent sections of the strip which would occur on cooling to a uniform temperature as a result of uneven temperature distribution across the strip 1, the operator then adjusts the profile of the fourth bending roll 10. The manner of adjustment is illustrated with reference to Figure 5.

Figure 5*a* illustrates a typical temperature distribution across the strip 1. As indicated, the strip 1 is hotter towards its centre than at its edges. If a strip which is level under these temperature conditions were allowed to cool to a uniform temperature, the centre section would contract more than the side sections leaving a strip with long or wavy edges. The length of the centre section of the strip must therefore be increased relative to the lengths of the edges to offset these differences in lengths.

The temperatures of the strip at six points across the width of the strip detected by temperature sensing unit 50 are indicated by points A to F on the graph in Figure 5*a*. On

observing the positive temperature differences between the central regions of the strip and the edges of the strip, the operator adjusts the profile of the flexible roller 10 until the deflections of the roller 10 from a linear profile corresponds, as far as possible, with the variations in temperature across the width of the strip as indicated in Figure 5*b*. The adjustment is effected by rotating the handwheels of the gearboxes 45. The rotation of each handwheel is transmitted to the pairs of lead screws 38 associated therewith via the main and intermediate drive wheels 45, 44 and 40. The rotation of the lead screws 38 in turn causes the wedges 35 to shift axially in the trough 31 beneath the base plates 29 thereby raising the associated bearings 27, 28. As a result the relative radial dispositions of the backing rollers 20 can be adjusted at four different points along the length of the flexible roller 10, so that the profile of the flexible roller 10 can be adjusted to conform closely to the temperature profile of the strip.

In general, the deflection of the flexible roller 10 at any point will generally be directly proportional to the difference between the temperature of the strip at that point and the temperature at a reference point such as the edge of the strip. The amount of adjustment necessary in the flexible roller 10 for any given temperature difference between the centre and edges of the strip 1 will depend upon the properties of the material, for example the coefficient of linear thermal expansion and Young's Modulus, and on the physical construction and operating conditions of the apparatus itself, for example the differences between the flexible roll 10, the bending roll 9 and the third deflector roll 11, and the amount of stretching produced between the bridle rolls 4, 5, 12, 13. In any particular case, the exact relationship between the temperature distribution in the strip and the necessary deflection of the roller 10 could either be approximated mathematically, or determined empirically. Once the relationship has been determined, flexible roller 10 could be controlled automatically by utilizing electrical output signals from the temperature sensors to control drive motors for the gearboxes 45. Suitably, the movement of the wedges could be arranged to generate a feedback signal, for example by means of a linear potentiometer operated by the movement of the wedges, which signal offsets the temperature signal until a null point is reached.

In the apparatus described above the backing rolls of the flexible roller 10 are adjusted in groups of four. Finer control over the profile of the flexible roller 10, may be achieved by arranging the backing roller for individual adjustment. The time consumed in effecting adjustment of the roller 10 will however be increased proportionately.

WHAT WE CLAIM IS:—

1. A method of producing strip material which comprises rolling strip material to a desired thickness, placing the rolled strip under tension, measuring the temperature of the strip material at selected points across its width and stretching the strip material non-uniformly across its width by amounts dependent upon the temperature measurements and sufficient to reduce or eliminate differences in the lengths of adjacent longitudinal sections of the strip material which would otherwise occur on relasing the tension and on cooling the strip material to a uniform temperature.

2. A method according to claim 1 wherein the stretching is effected by subjecting the strip material, whilst under tension, to a plurality of bend reversals about axes transverse to the strip and adjusting the transverse profile to which the strip is bent in at least one of the bend reversals by an amount dependent upon said temperature measurements so that the relative lengths of adjacent longitudinal sections of the strip material are increased sufficiently to offset differences in their lengths which would otherwise occur on bringing the strip to a uniform temperature.

3. A method according to claim 2 wherein the temperature across the strip material is measured by a temperature sensing unit, output signals from which are used automatically to control the transverse profile at said at least one bend reversal.

4. Apparatus for producing strip material comprising means for rolling the strip material to a desired thickness, means for placing the rolled strip under tension, means for measuring the temperature of the strip material at selected points across its width, said means for placing the strip under tension including a plurality of transverse bending rolls, at least one of which may have its profile adjusted in dependence upon said temperature measurements, and means for drawing rolled strip material in a longitudinal direction over the bending rolls whilst under tension.

5. Apparatus according to claim 4 wherein the or each adjustable profile roller comprises a flexible roller rotatably mounted in fixed end supports and supported along its length by a plurality of backing rolls, and means for adjusting the relative radial dispositions of the backing rolls in dependence upon said temperature measurements.

6. Apparatus according to claim 5 wherein the flexible roller is supported between backing rollers rotatably mounted on two parallel flexible shafts, each supported along its length by a plurality of bearings movable radially relative to each other by means of reciprocable wedges.

7. Apparatus according to claim, 5 or 6 wherein the output of the temperature sensing means is used automatically to control the

adjustment of the profile of the or each said flexible roller.

8. A method of producing strip material substantially as described herein with reference to the accompanying drawings.

9. Apparatus for producing strip material substantially as described herein with reference to the accompanying drawings.

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COMPLETE SPECIFICATION

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SHEET 1

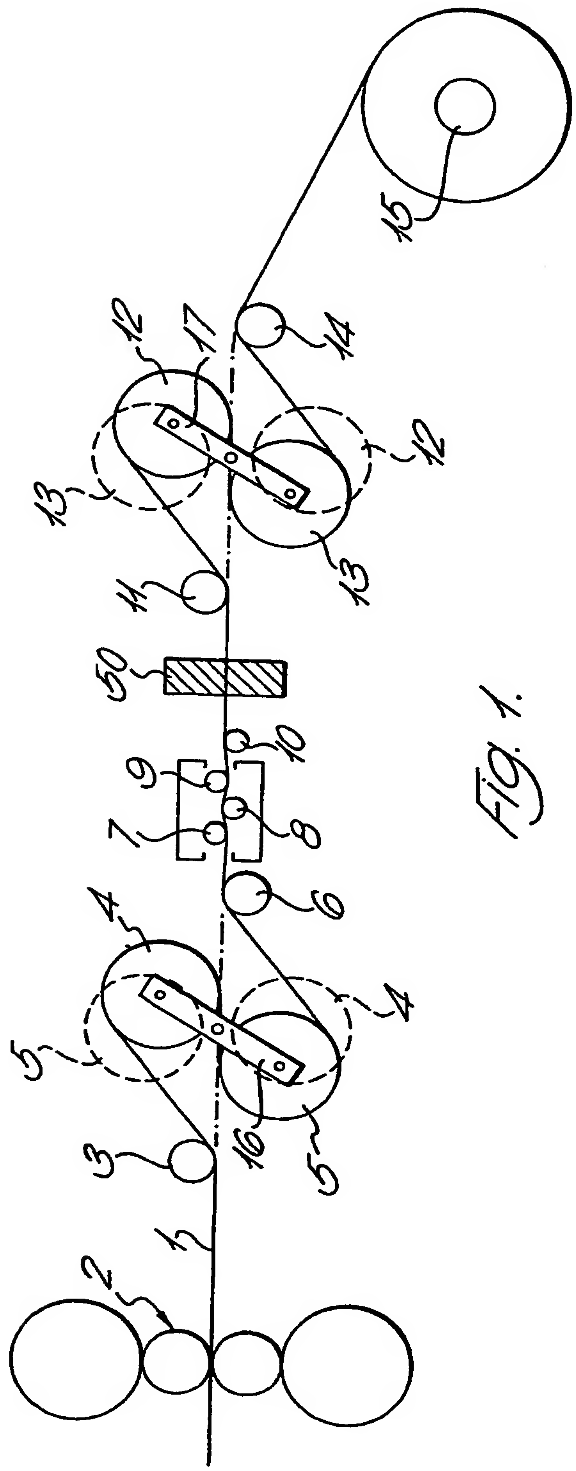

Fig. 1.

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SHEET 2

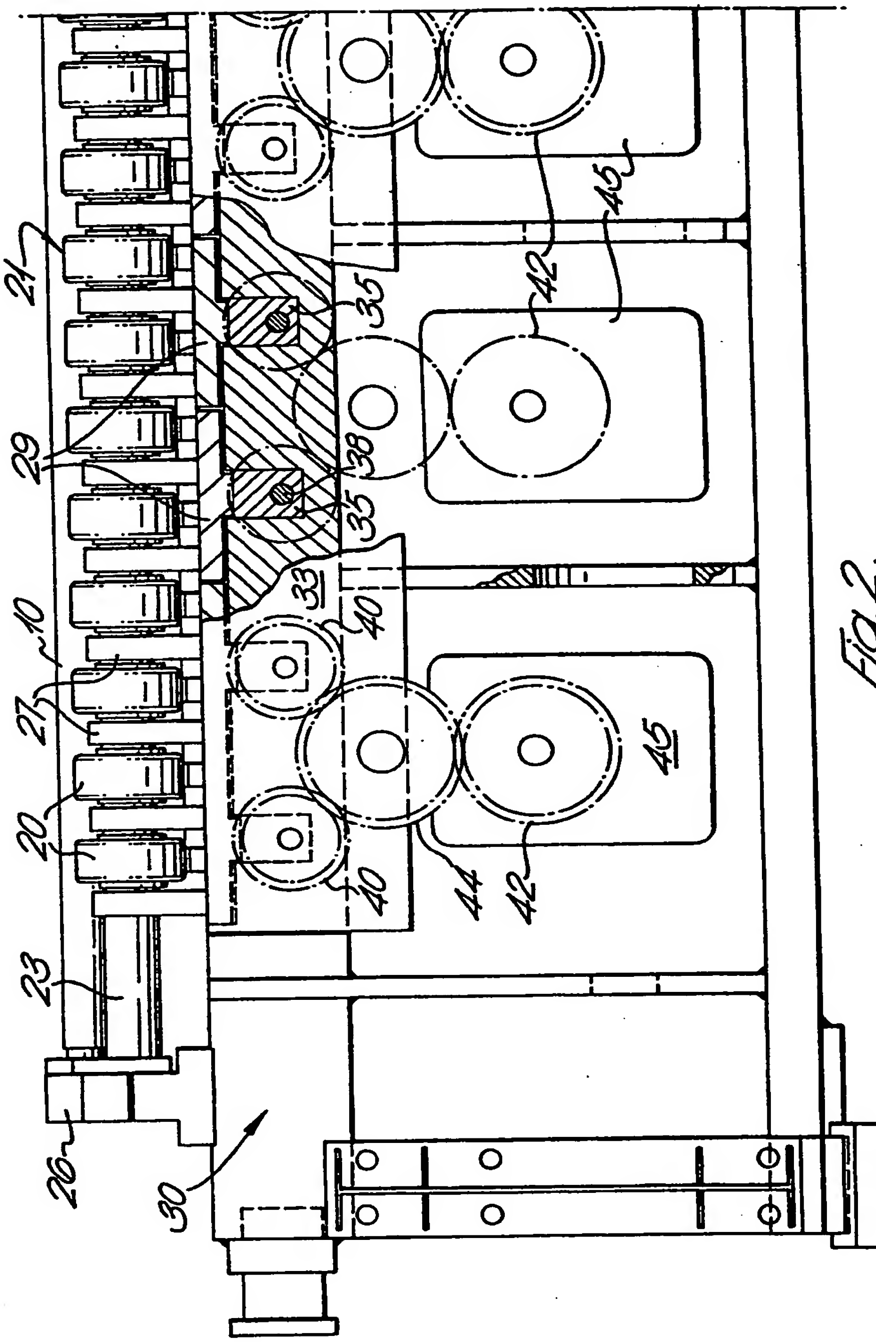

Fig. 2.

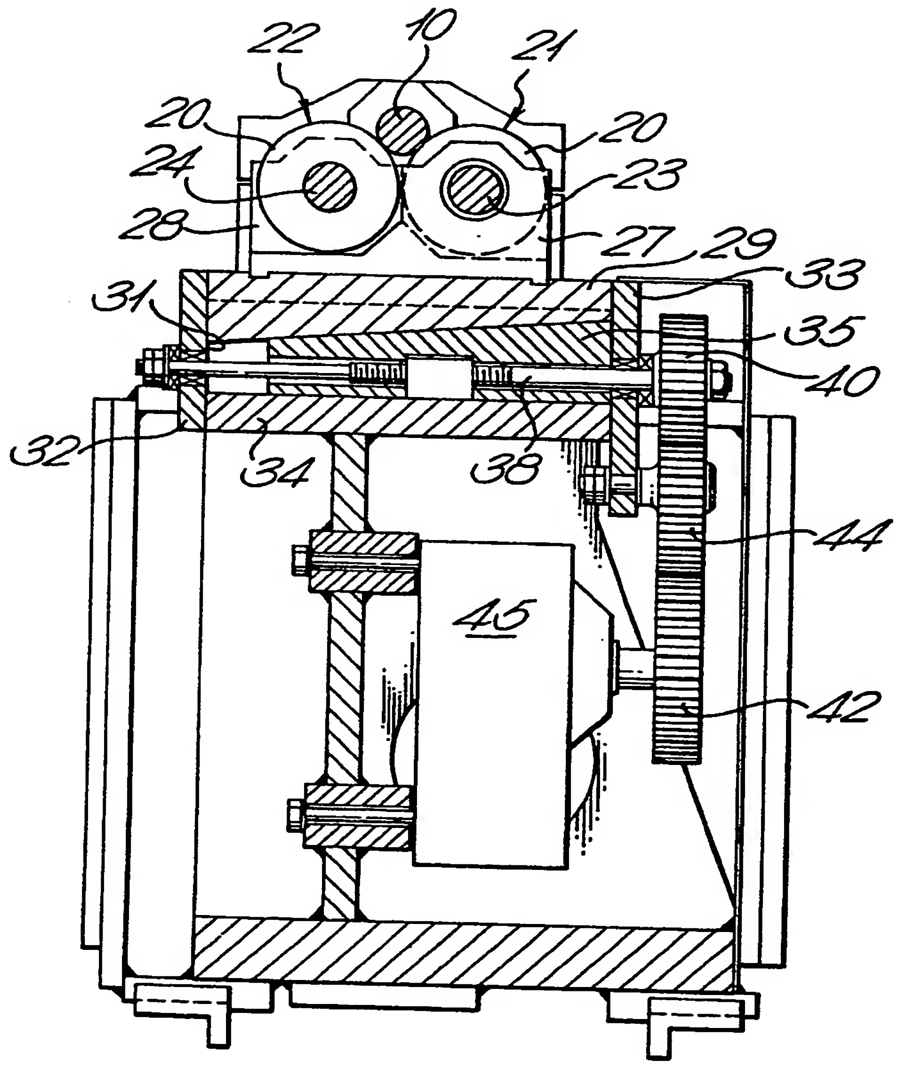

Fig. 3.

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SHEET 4

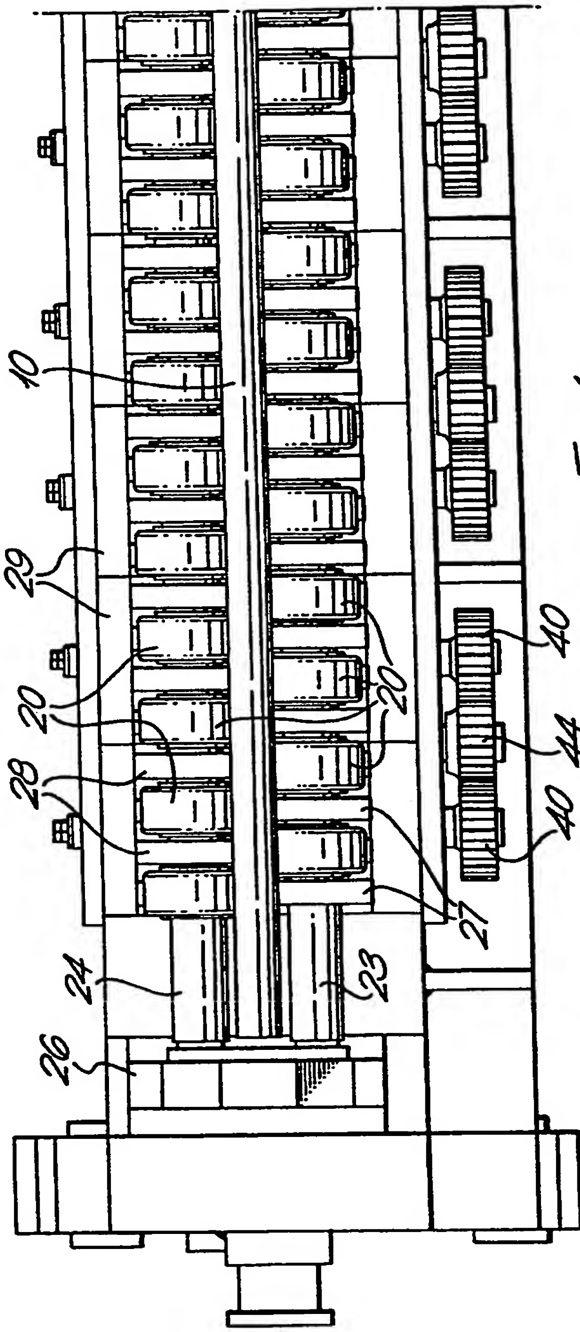
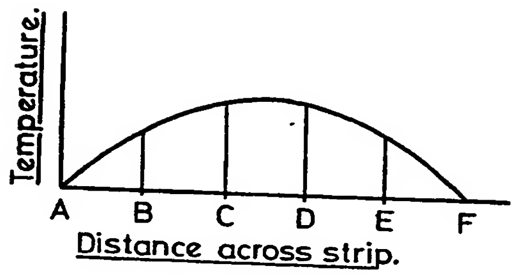


Fig.4.

Fig. 5a.



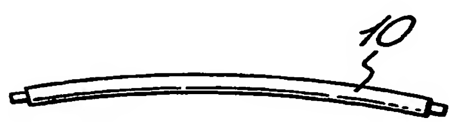


Fig. 5b.